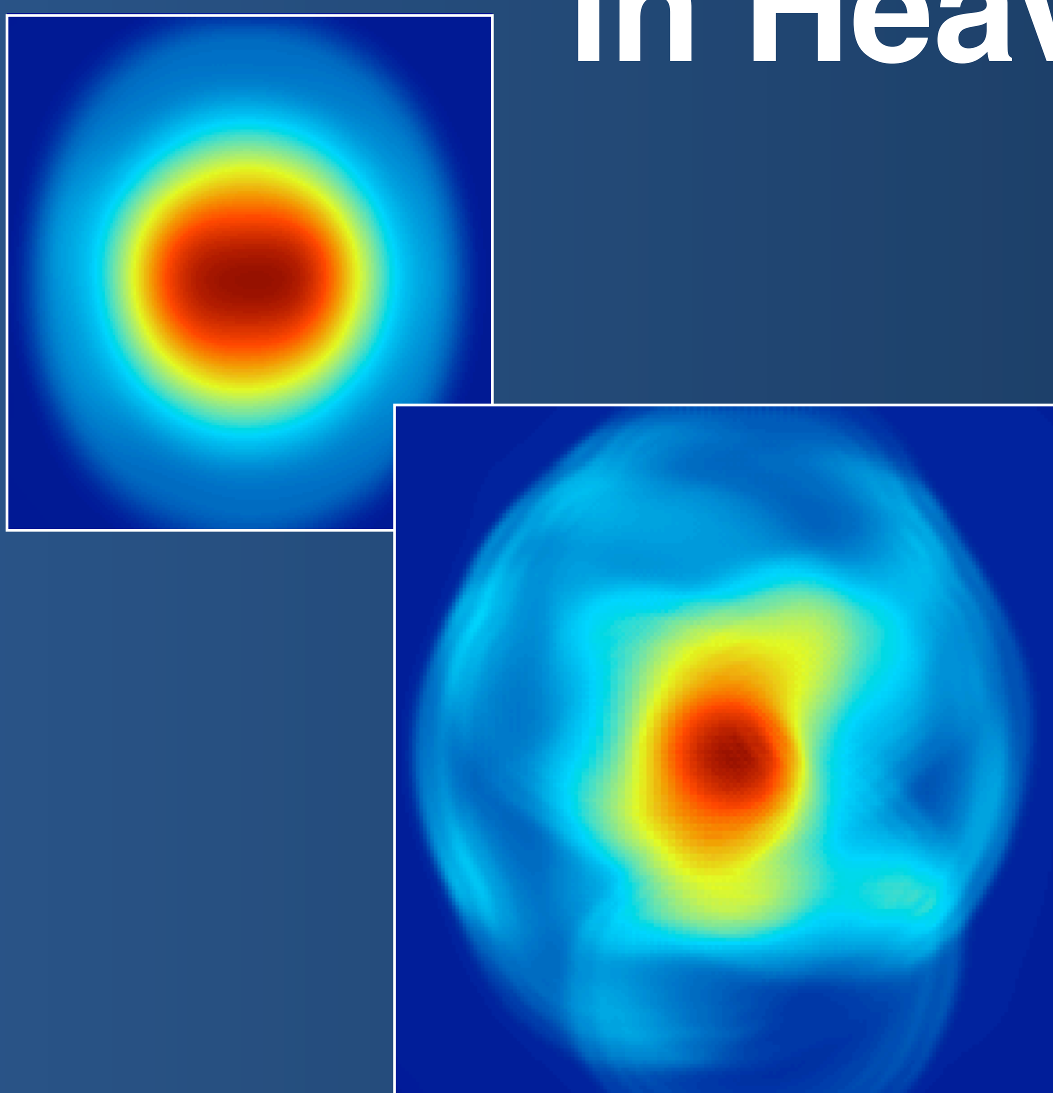
Joint CATHIE / TECHQM Workshop
December 14-18, 2009

University of Colorado Nuclear Physics

Fluctuating Initial Conditions in Heavy Ion Collisions



McCumber, Mendoza, Nagle
University of Colorado

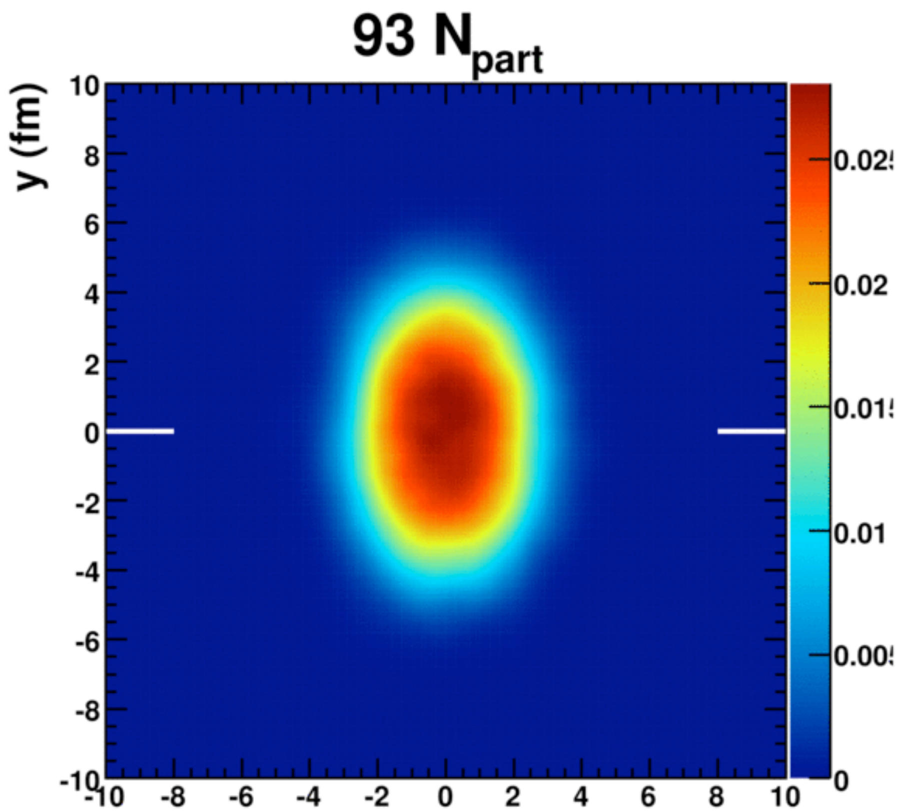
CATHIE/TECHQM Workshop
15 December 2009

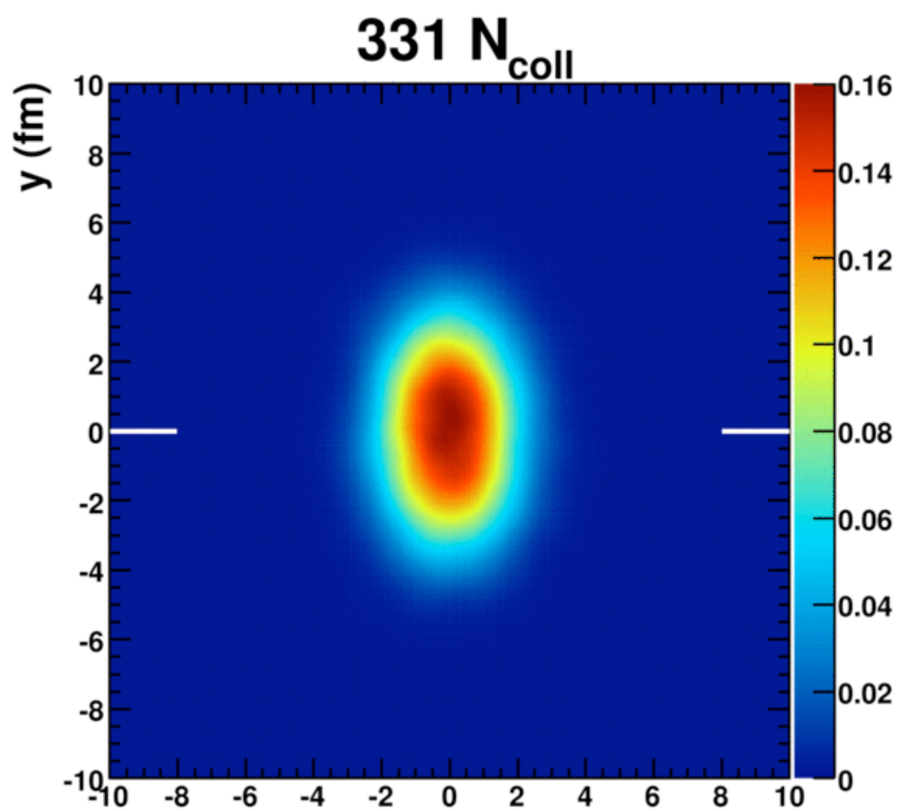
Event Fluctuations (I)

PHOBOS
Glauber MC v1.1

b = 9.3 fm
(20-60%)

1000 events





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Glauber MC v1.1

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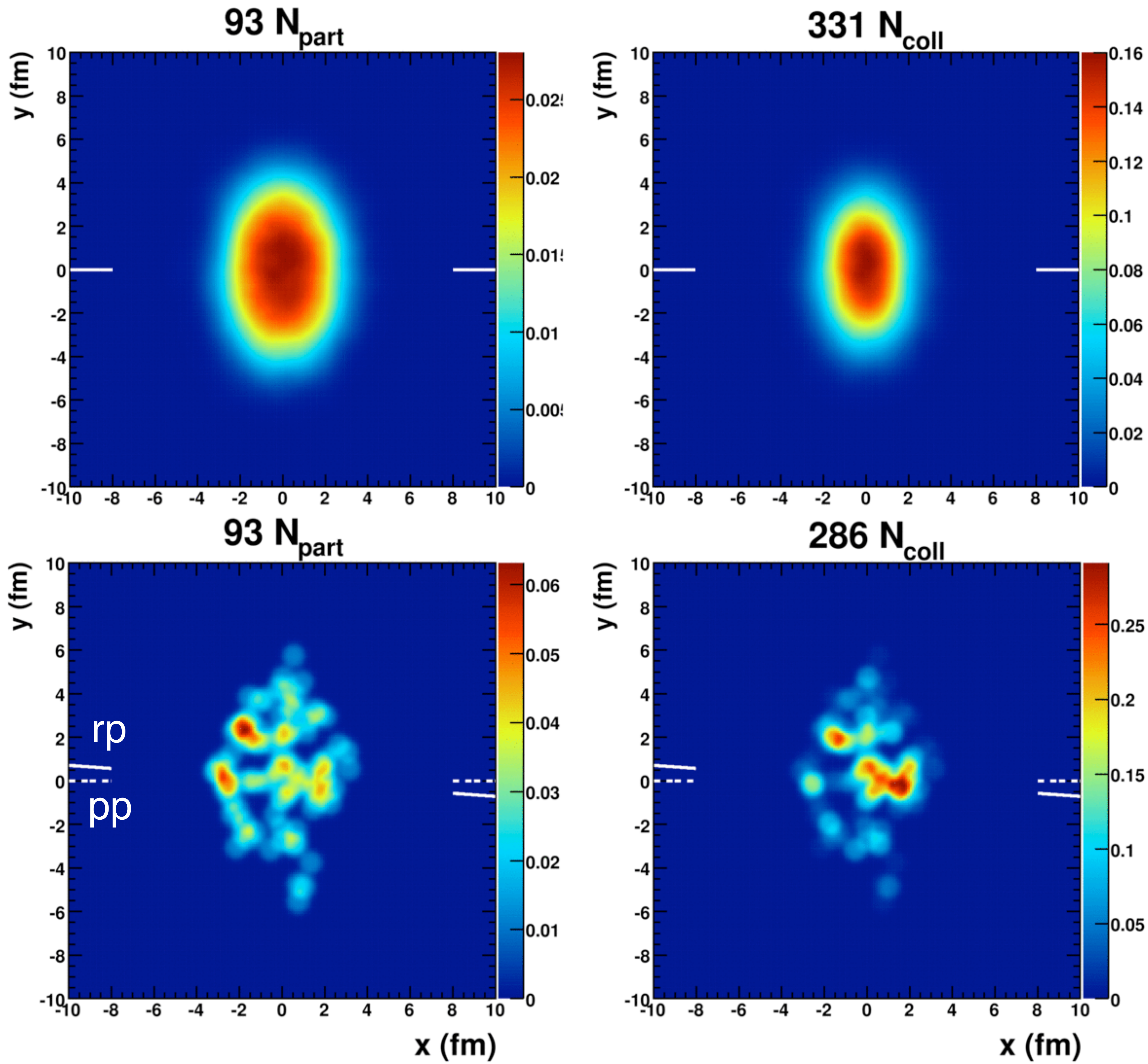
(20-60%)

<u>1000 events</u>

<u>Single event</u>



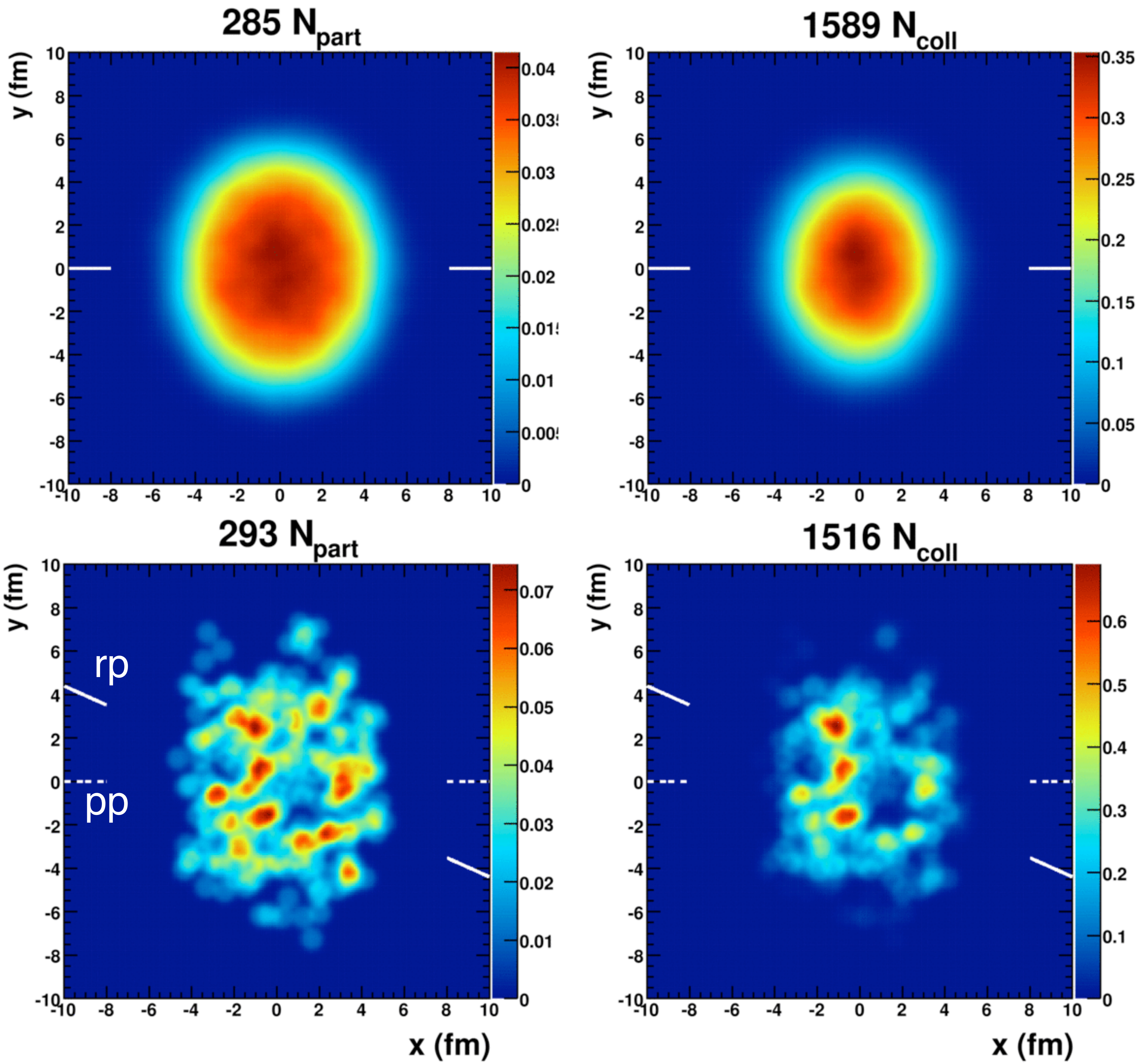
The smooth “almond” at RHIC is a myth

Event Fluctuations (II)

b = 4.4 fm
(0-20%)

<u>1000 events</u>

<u>Single Event</u>



Central collisions still don’t well-sample the overlap

Talking the Talk...

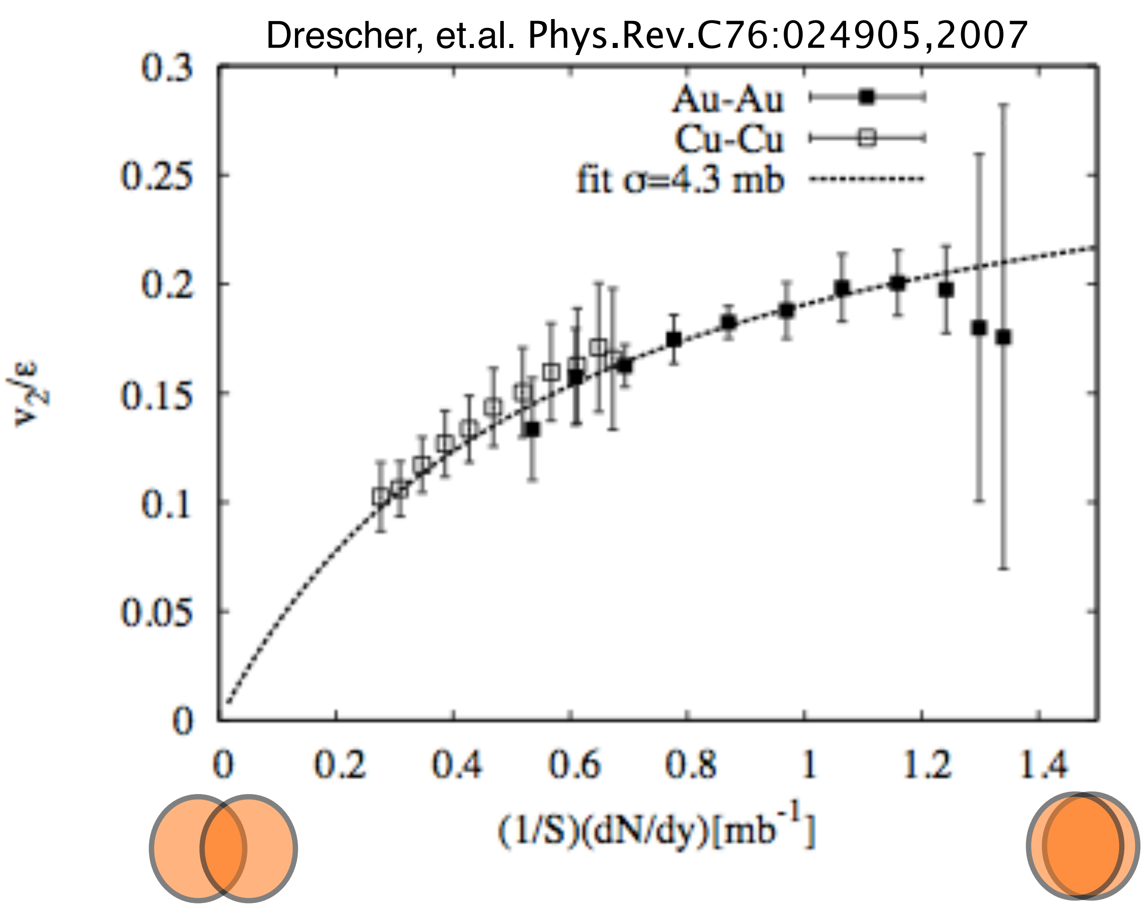
CATHIE/TECHQM Day 1: *"Modeling event-to-event fluctuations is important in the extraction of viscosity"*

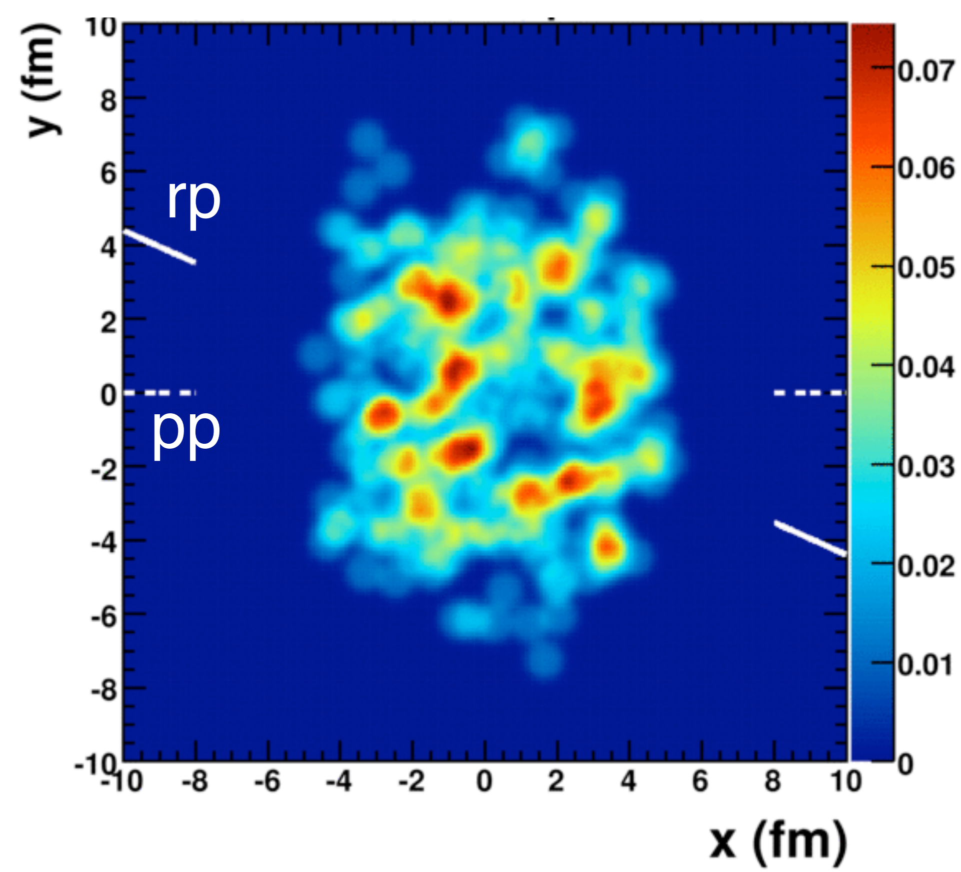
Viscosity (η/s) Extraction:

(1) **Knudsen** modeling of viscous corrections
- fluctuations change ϵ

My focus today

(2) **Simulation** of viscous hydrodynamics
(a) fluctuations change ϵ
(b) event-to-event, ε(x,t=0)



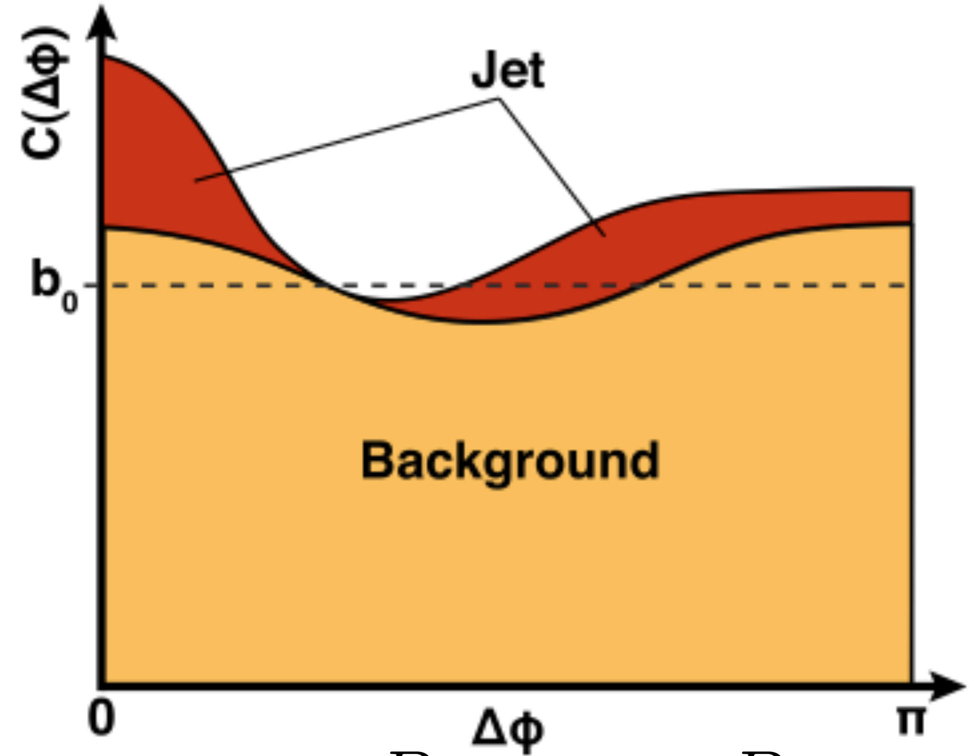


...Walking the Walk

Two-Source Model in Two-Particle Correlations:

$$C(\Delta\phi) = J(\Delta\phi) + B(\Delta\phi)$$

All pairs = Jet +
Event-wise Correlations



$$B(\Delta\phi) \sim (1 + 2v_2^A \cos(2\phi^A) + ...) \otimes (1 + 2v_2^B \cos(2\phi^B) + ...)$$
$$\sim (1 + 2c_2^{AB} \cos(2\Delta\phi) + 2c_4^{AB} \cos(4\Delta\phi) + ...)$$

In principle, event fluctuations can create v_3 in a single event

$$v_3 \longrightarrow 2c_3^{AB} \cos(3\Delta\phi)$$

Important: Current ridge and shoulder (aka "cone") results at intermediate p_T require small event-wise values of v_3

Yet, no estimates (experimental or theoretical) exist...

...hydrodynamic simulations with fluctuations could predict v_3

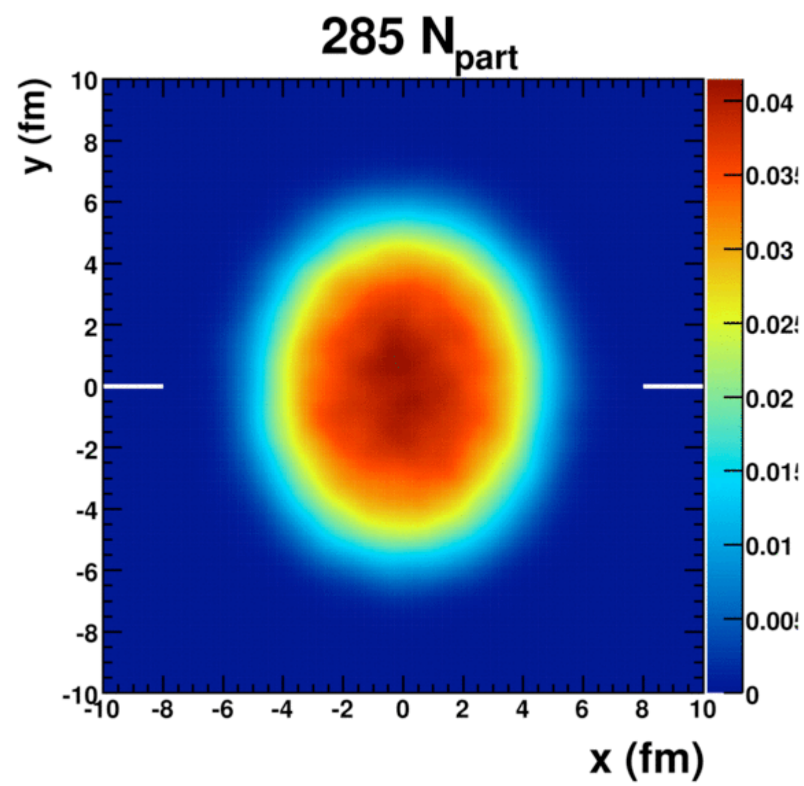
Defining Hydro Initial Conditions

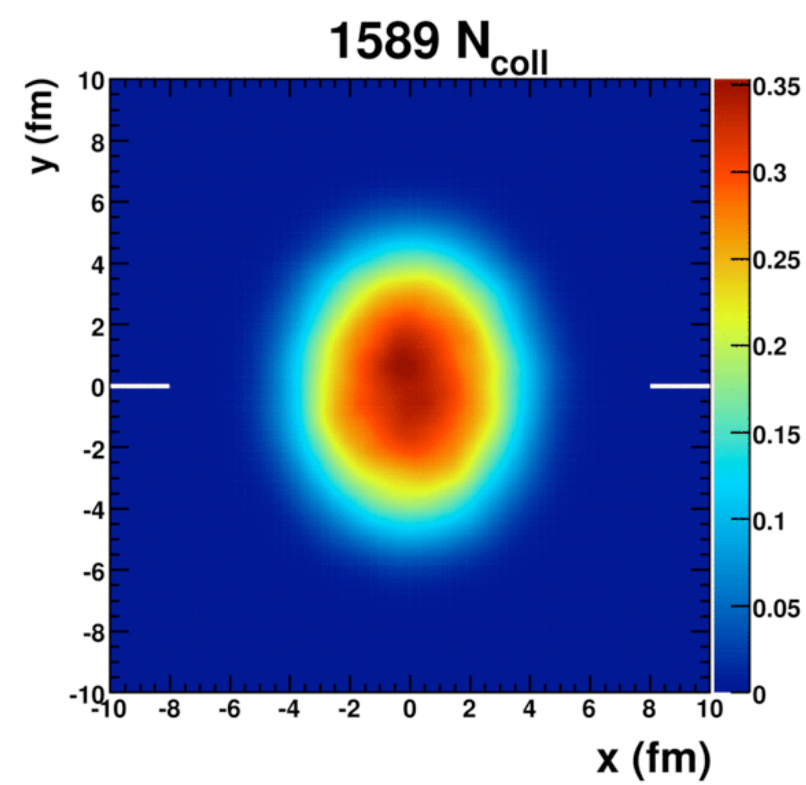
N_{part} vs N_{coll}

$$\frac{dN_{ch}}{d\eta} = n_{pp}\left[(1-x)\frac{N_{part}}{2} + xN_{coll}\right]$$

$$x = 0.13 \pm 0.01(stat) \pm 0.05(sys)$$

PHOBOS, B. B. Back *et al.*, Phys. Rev. **C70**, 021902 (2004), nucl-ex/0405027.

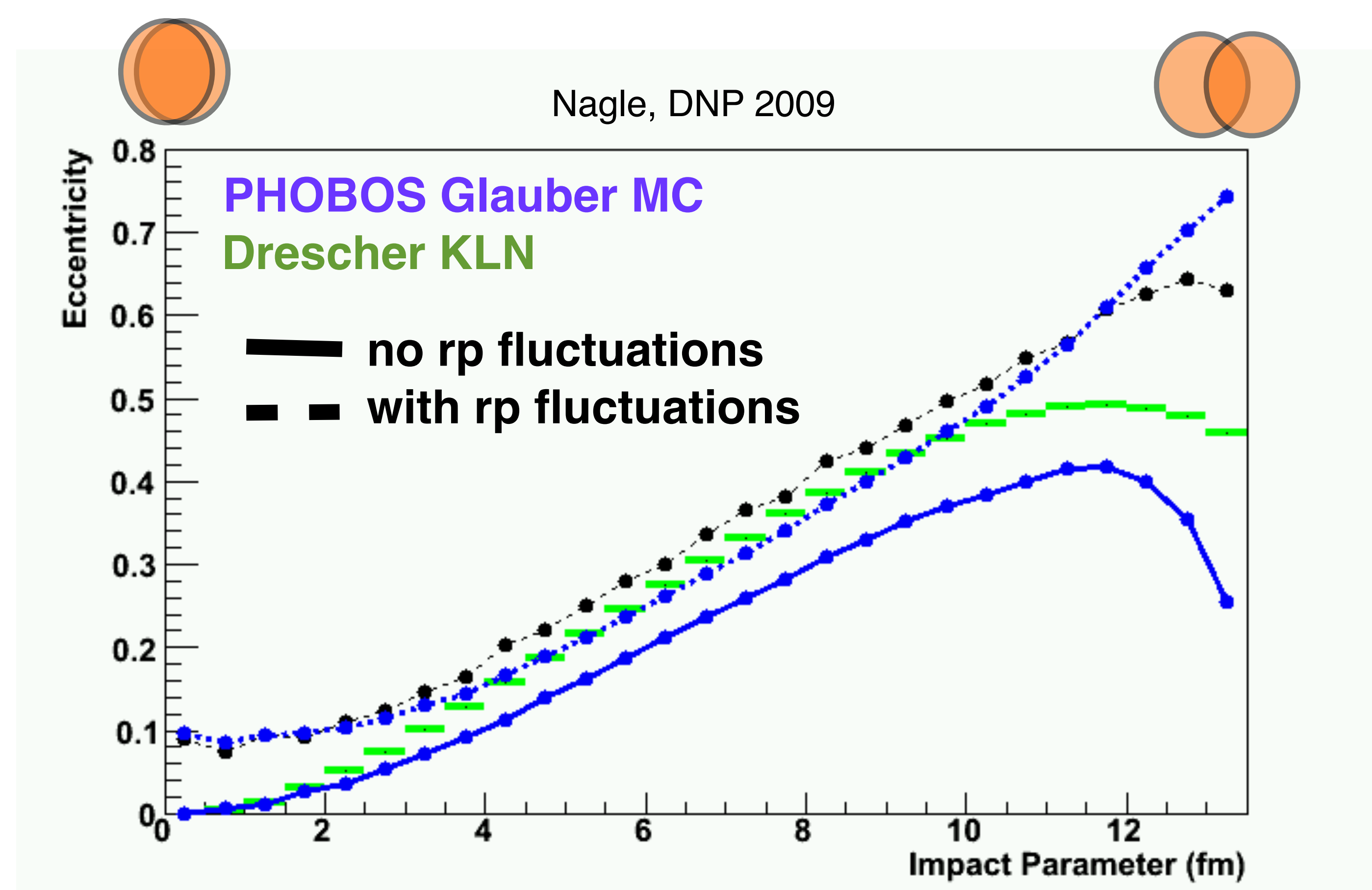




Glauber vs CGC

changes the eccentricity

correct selection remains an open question



Initial State Descriptions

Optical Glauber vs CGC (fKLN)

Large percentage difference (~60%) between Optical Glauber and fKLN eccentricity

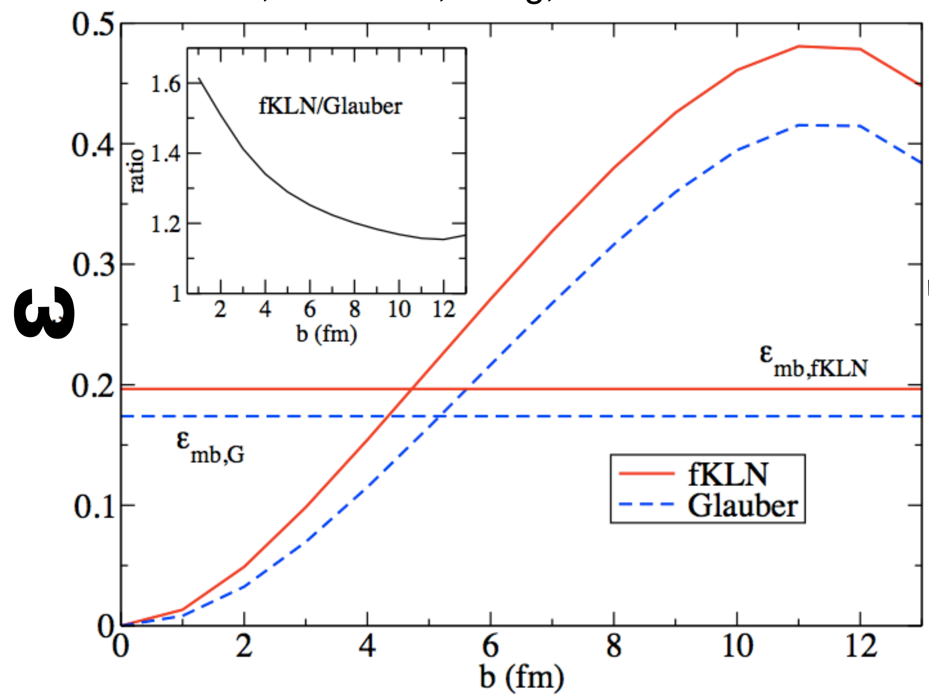
Scaled v_2/ε show characteristically different trends between descriptions

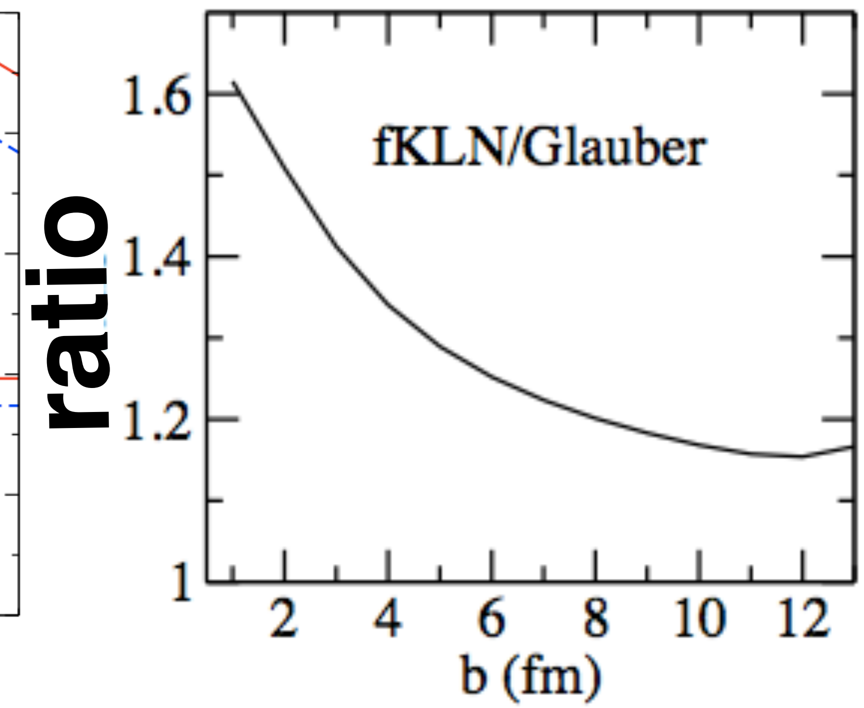
Data fall monotonically regardless of description

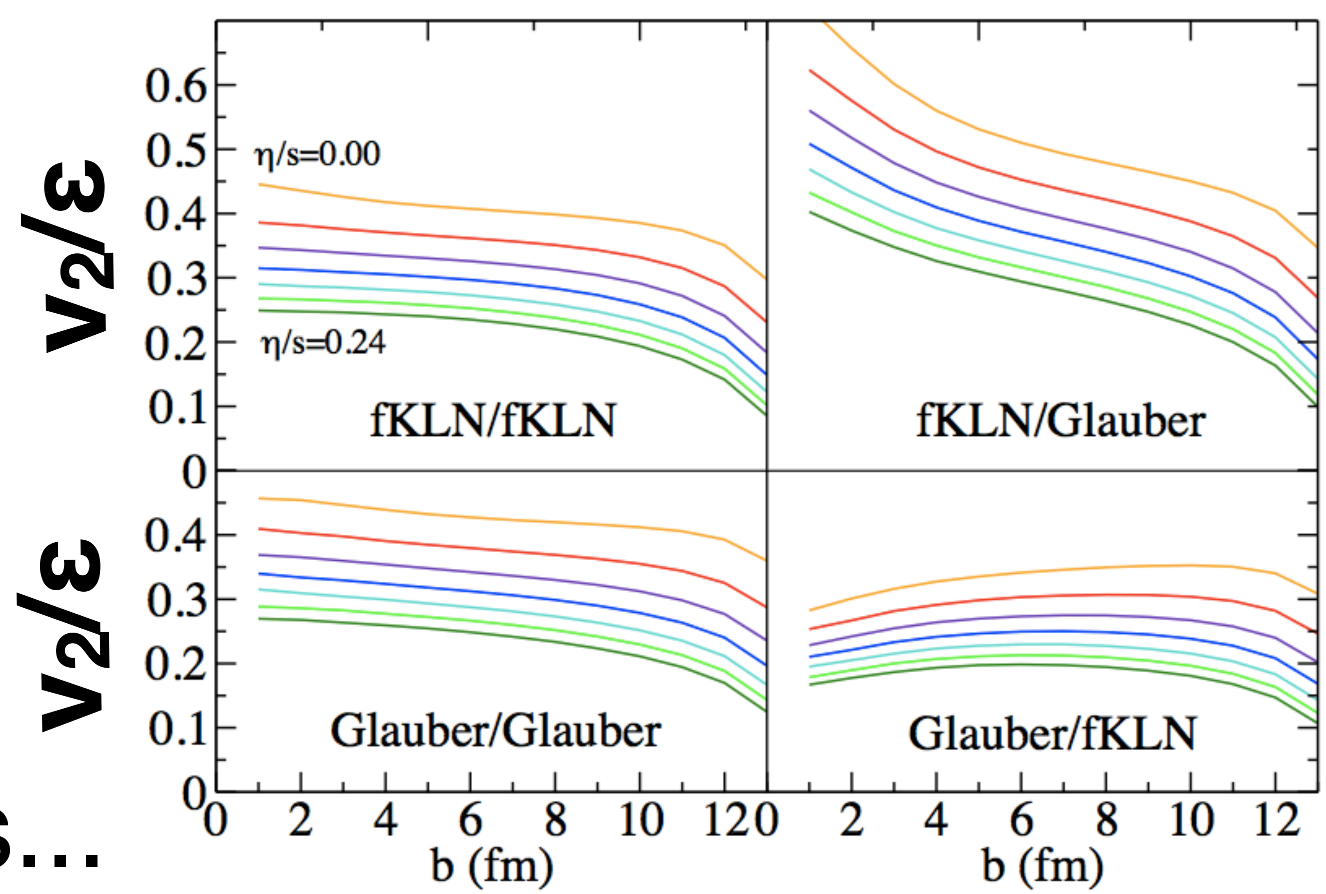
“appear to exclude... Glauber initial conditions”

Neglects fluctuations...

Heinz, Moreland, Song, arXiv:0908.2617v2







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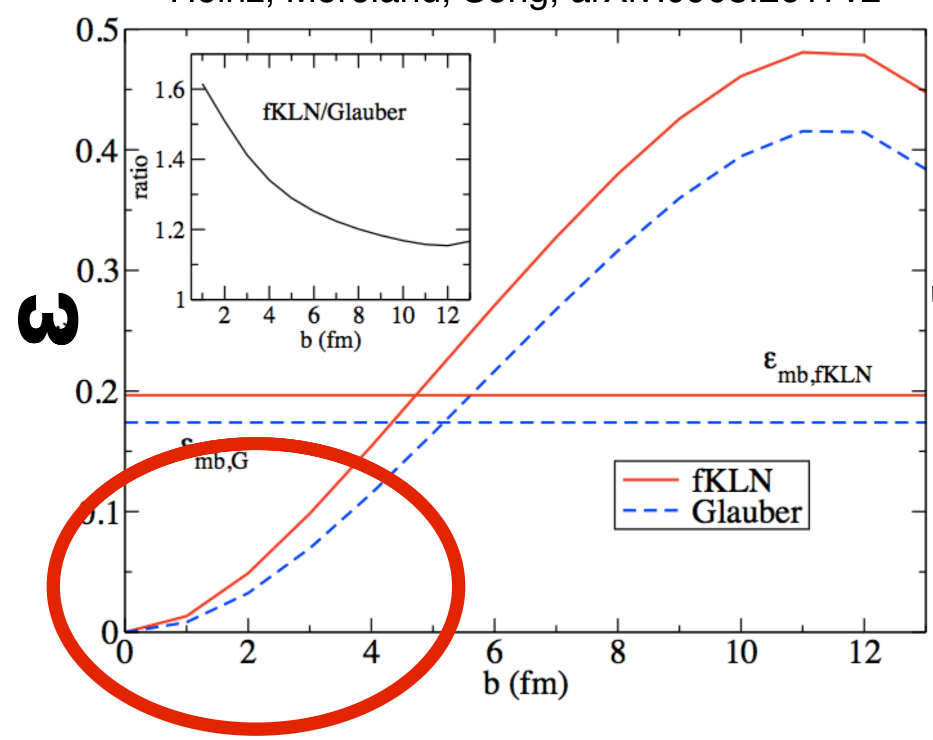

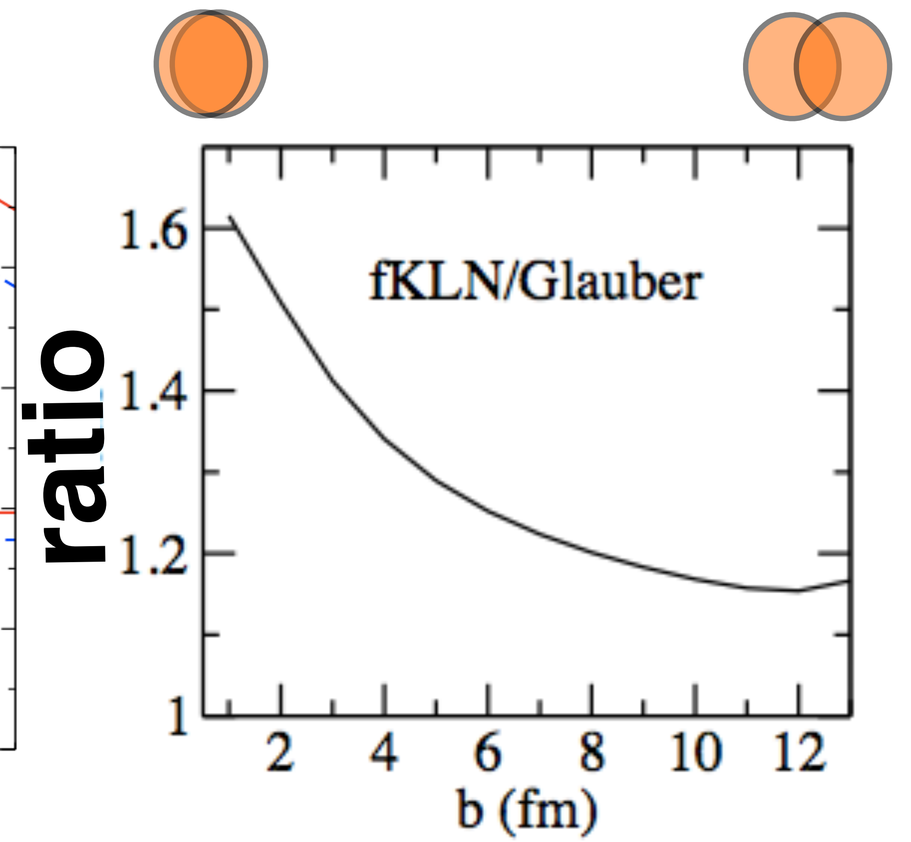

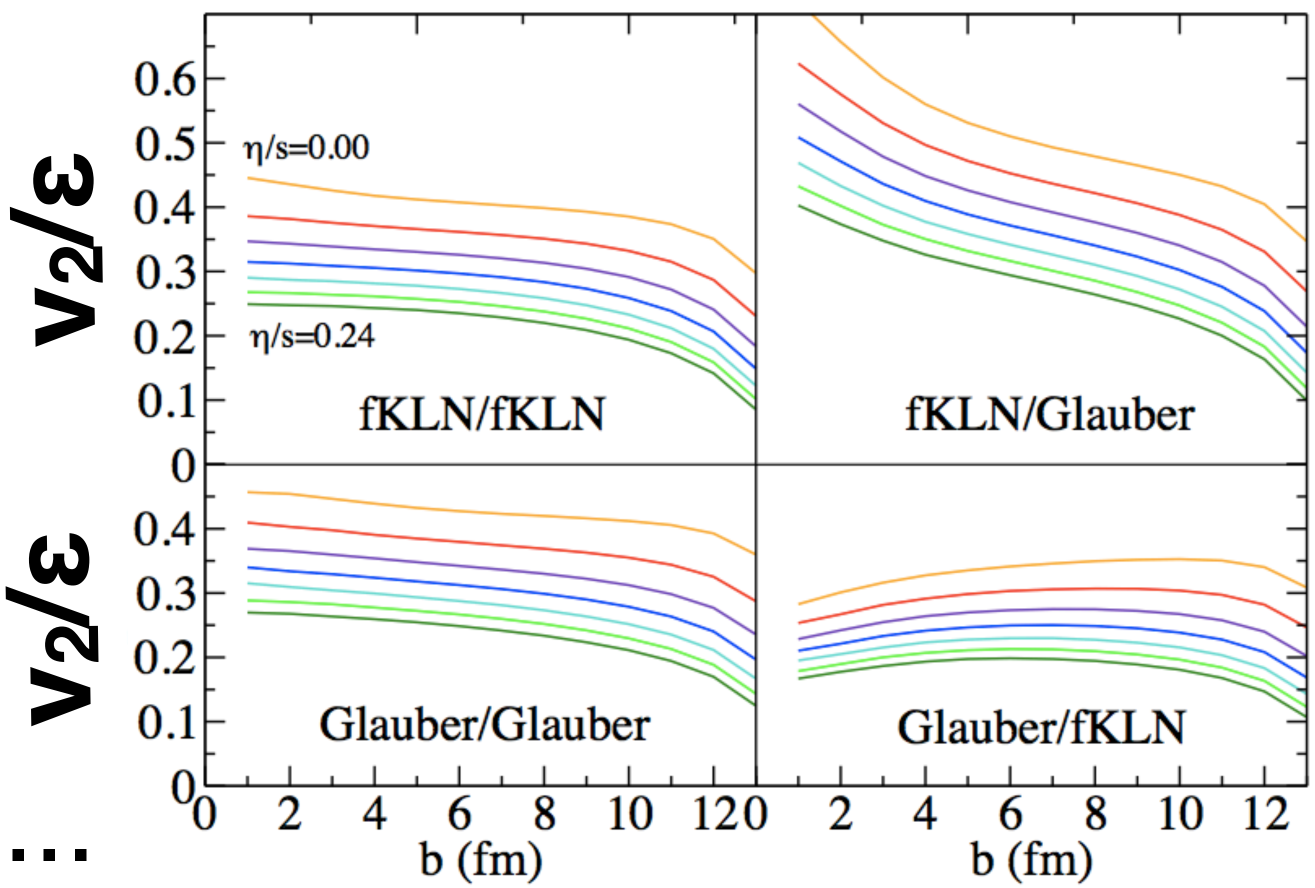

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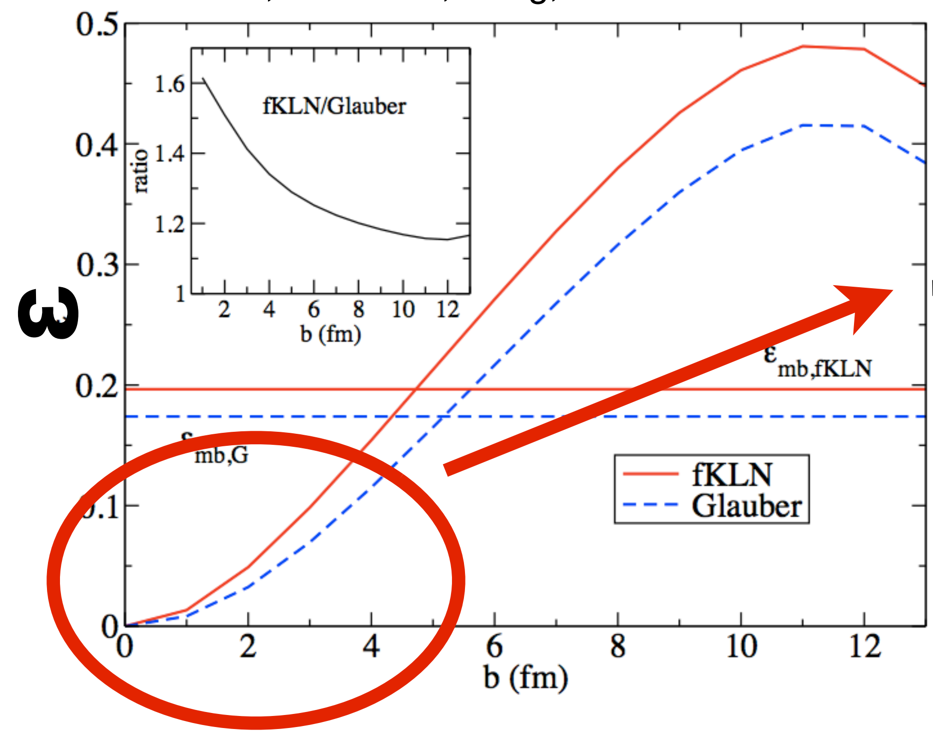

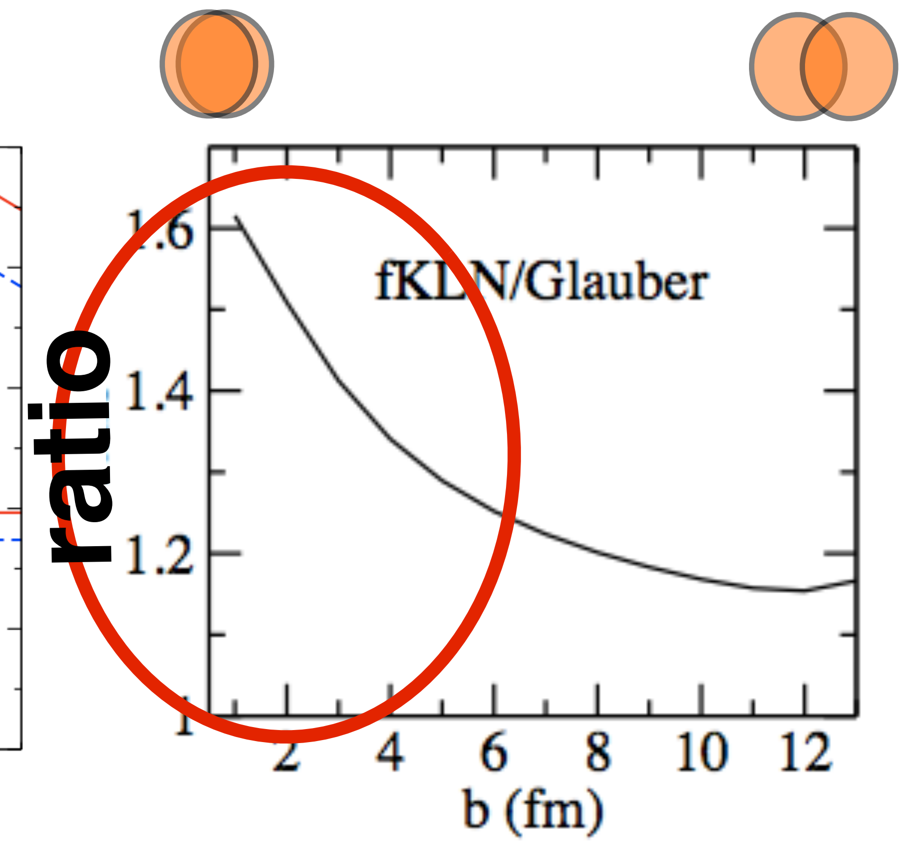

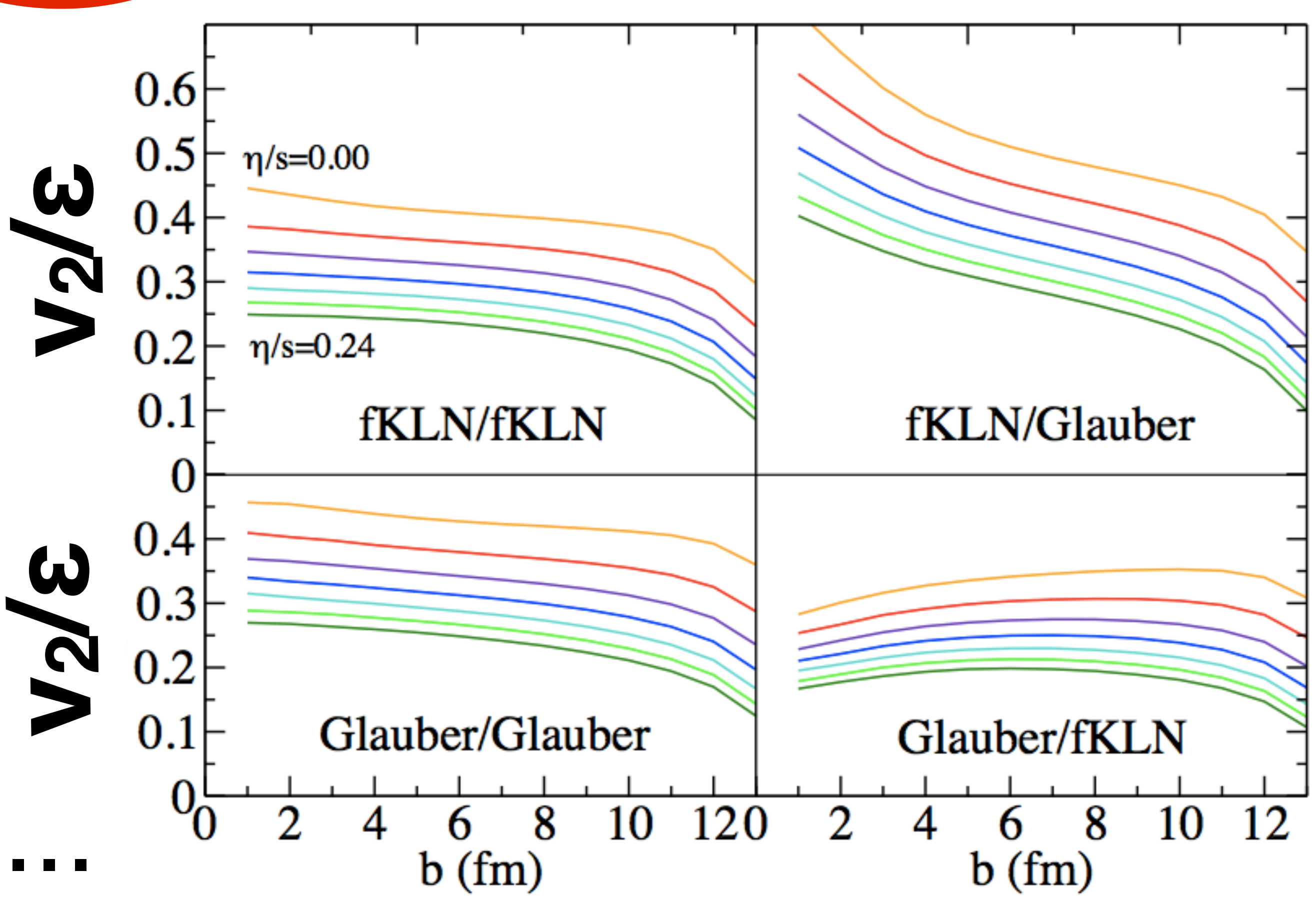

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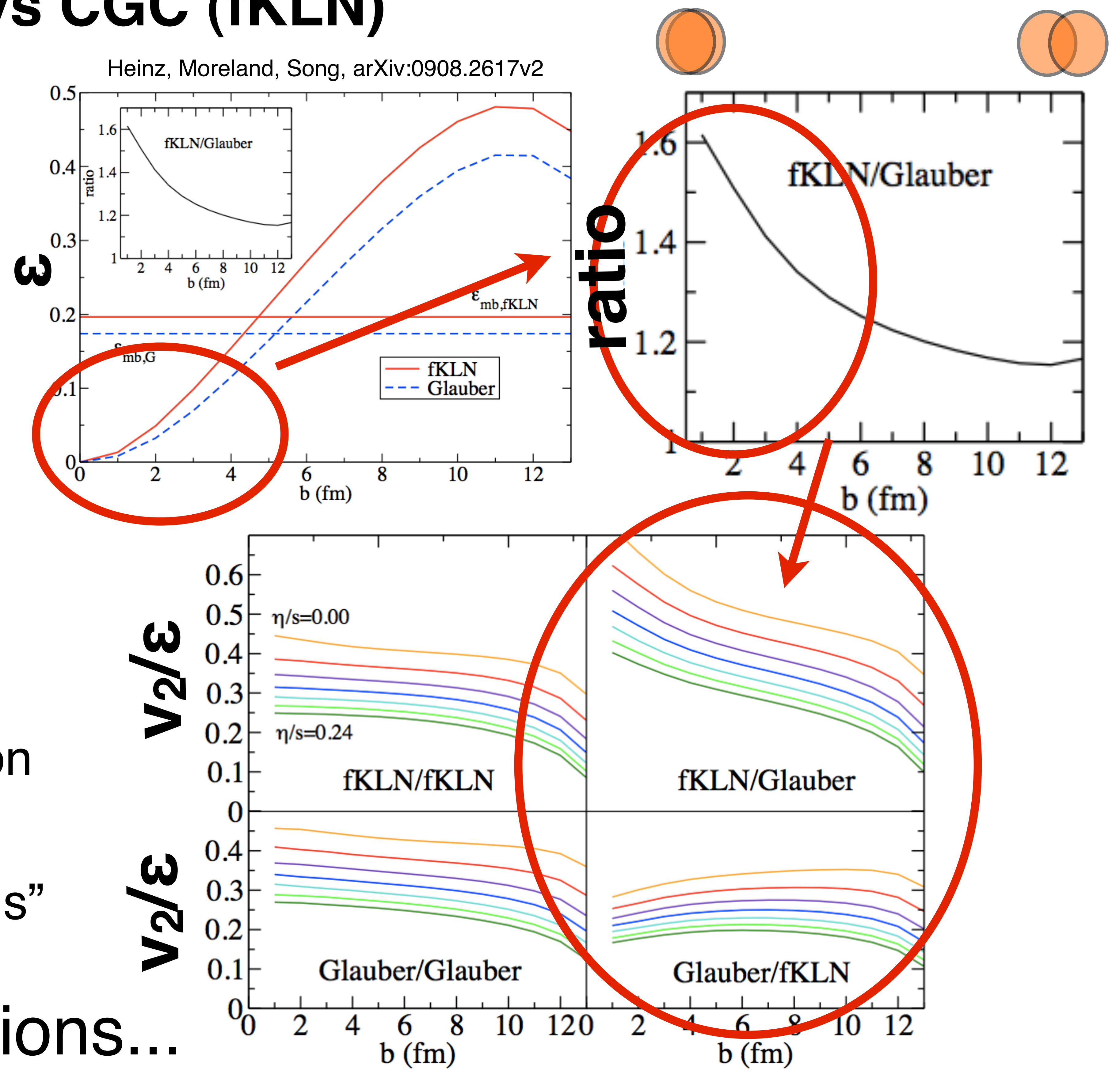
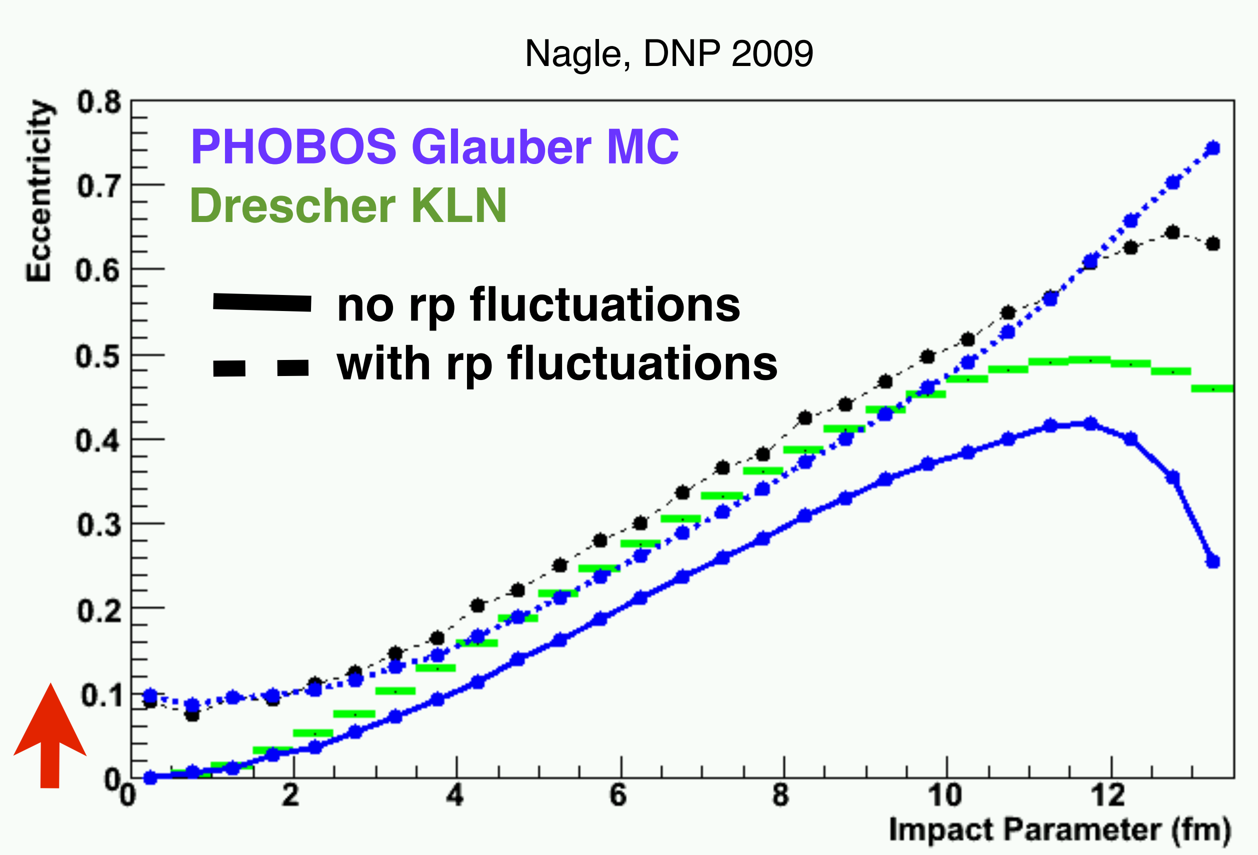


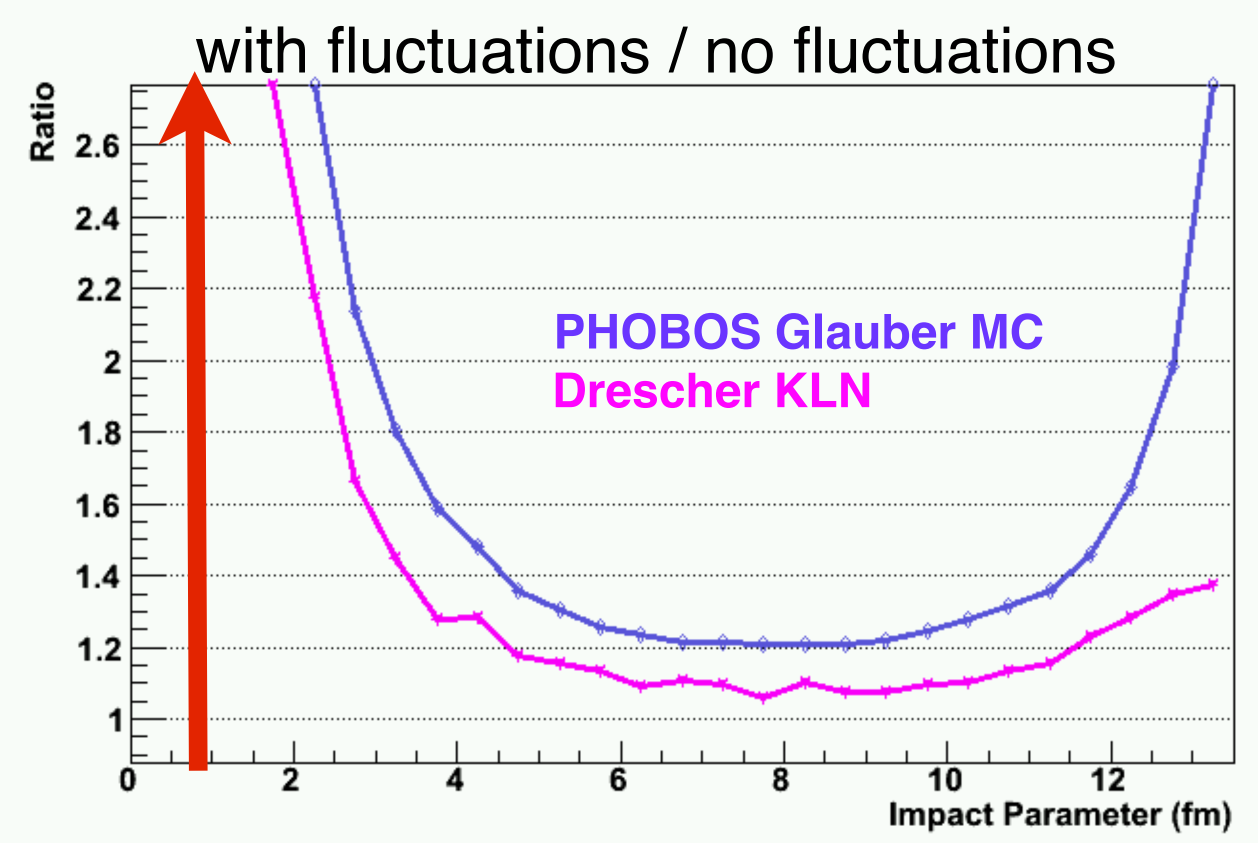
Adding Fluctuations

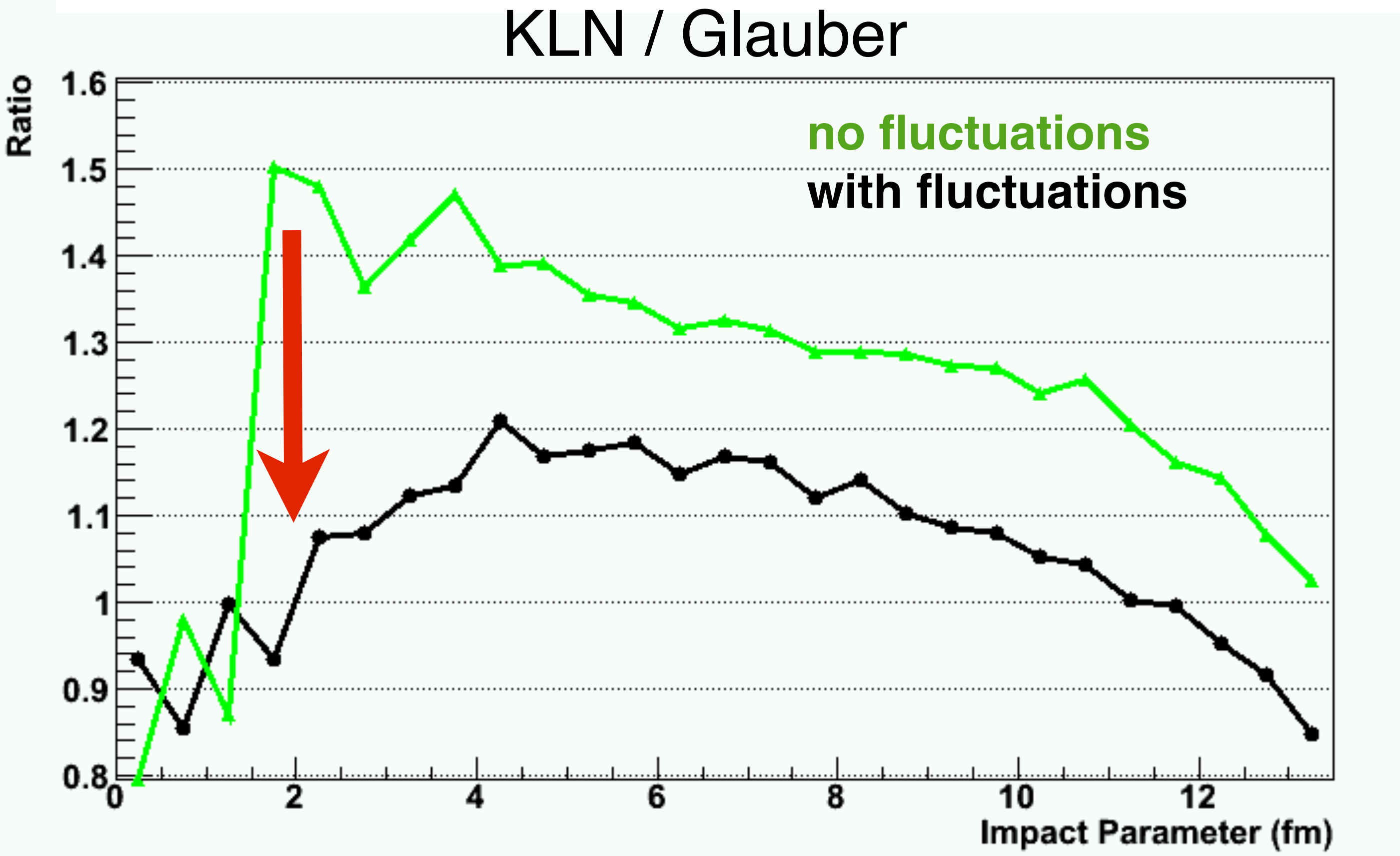


Event-to-event fluctuations dramatically increase central event eccentricity

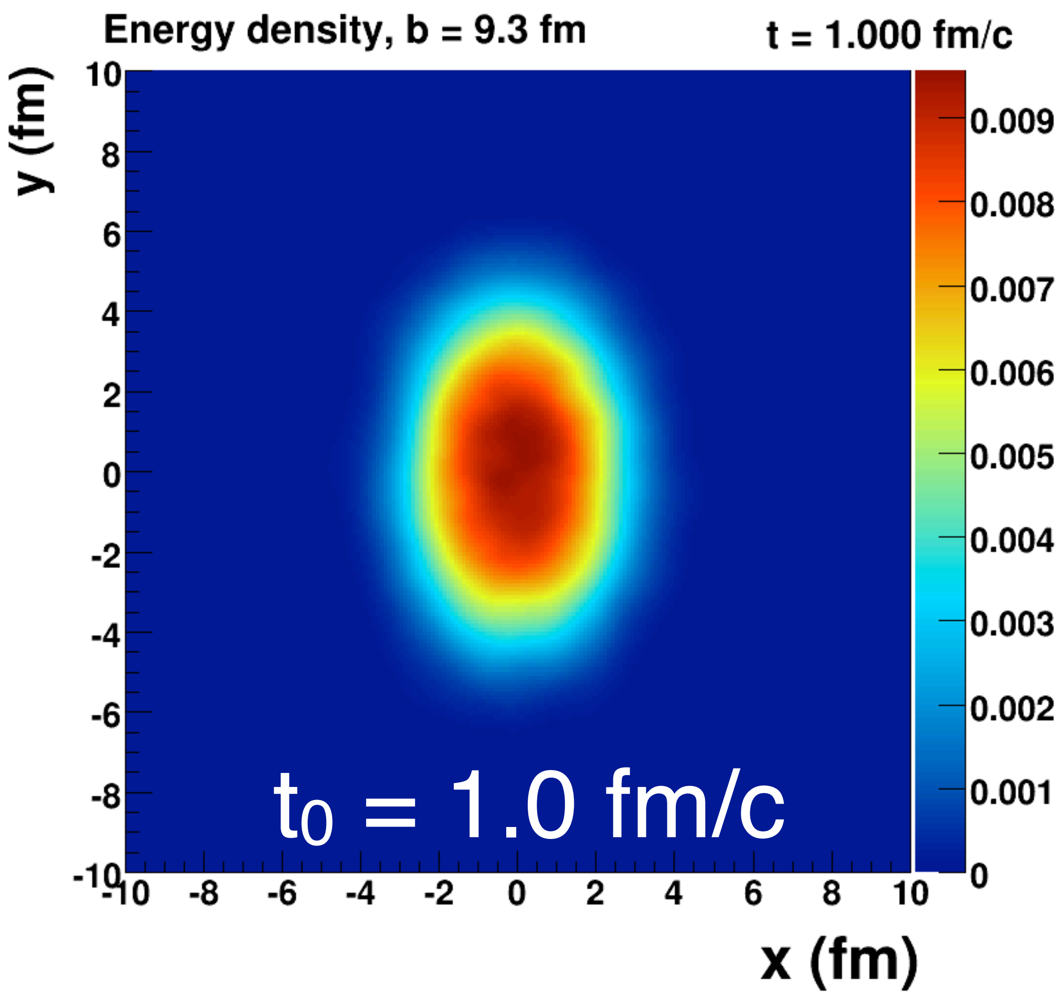
The effect overwhelms the intrinsic difference between CGC and Glauber

The point: Too early to bury Glauber on a qualitative comparison, yet a quantitative comparison may prove useful





Simulating Hydrodynamics



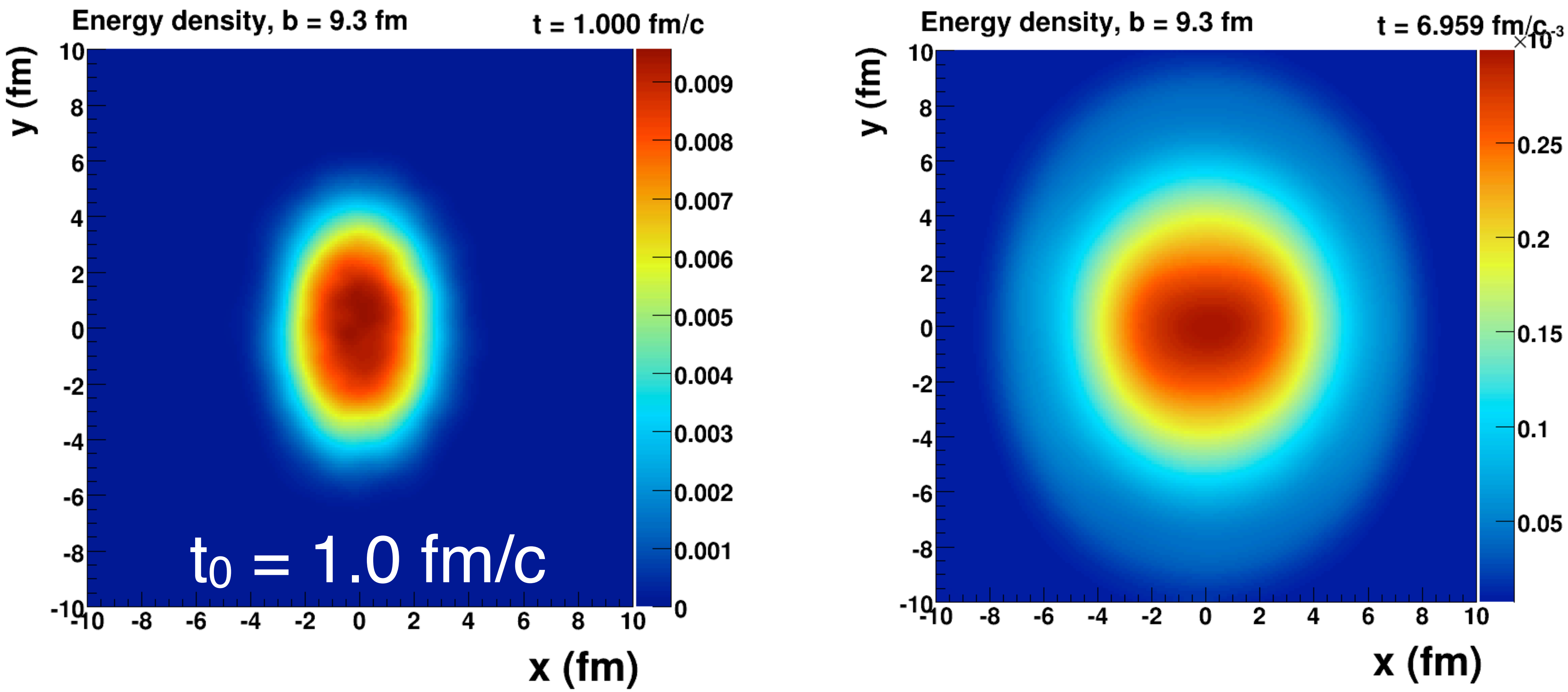
Viscous hydro code (v0.2) from M. Luzum and P. Romatschke
(http://hep.itp.tuwien.ac.at/~paulrom/codedown.html)(09001.488v1)

Settings: 200x200 grid, a=0.51 GeV^{-1}, η/s = 0.08

CPU Time: ~2.5 days/collision on Xeon 2.13GHz

Initial Geometry (N_{part}, x=0) from PHOBOS Glauber MC v1.1

Simulating Hydrodynamics



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Simulation Stages

initE - constructs the initial energy density distribution according to optical Glauber or fKLN

vh2 - relativistic hydro evolution and records the freezeout surface

convert - performs the freezeout

reso - resonance decay

extract - flow parameter extraction

Simulation Stages

Calculate energy density from Glauber MC

~~**initE** - constructs the initial energy density distribution according to optical Glauber or fKLN~~

vh2 - relativistic hydro evolution and records the freezeout surface

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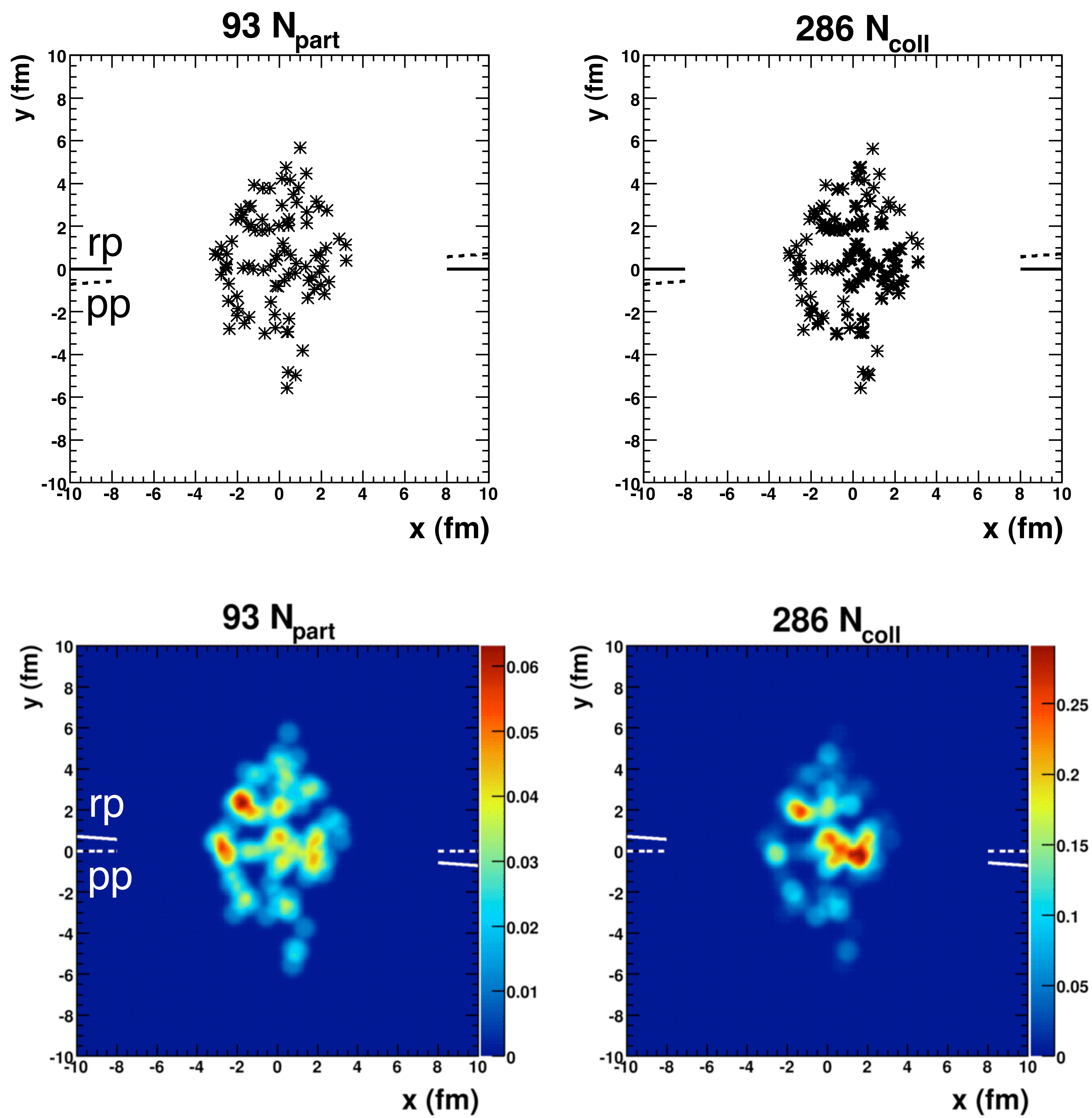
Preparing the Initial Condition

Distribution from PHOBOS Glauber MC

Rotate into the participant plane

Smooth each Glauber point with a Wood-Saxon (r_0 = 0.5 fm, d = 0.04 fm)

(If applicable, sum over many events)



Issues Encountered

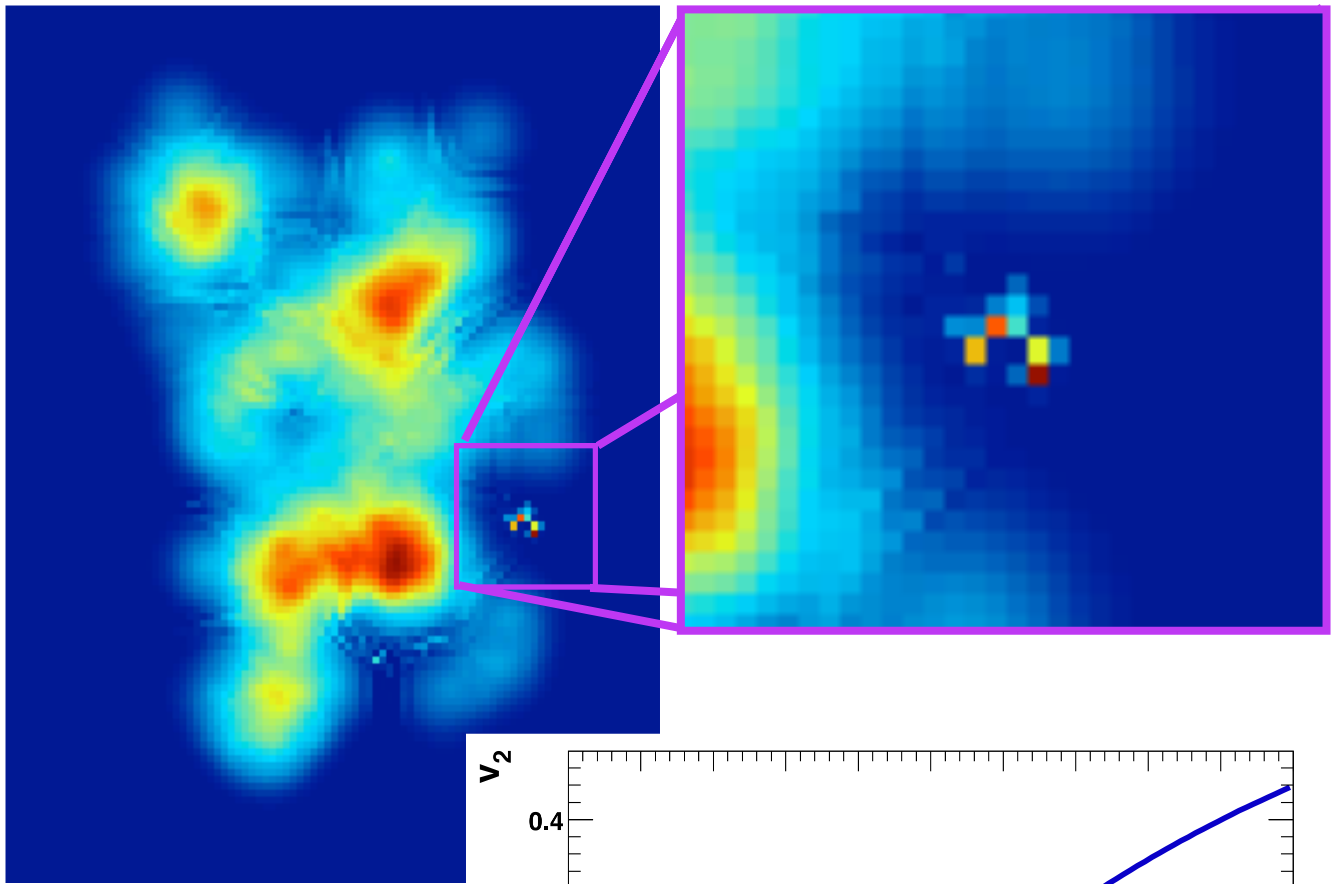
<u>Two obstacles:</u>

(1) Numerical error growth:

large percentage variations
in small density regions

results in spikes in the
energy density

(partial solution) **box smooth** in 3x3 grid
where density is low (< 0.01 peak)



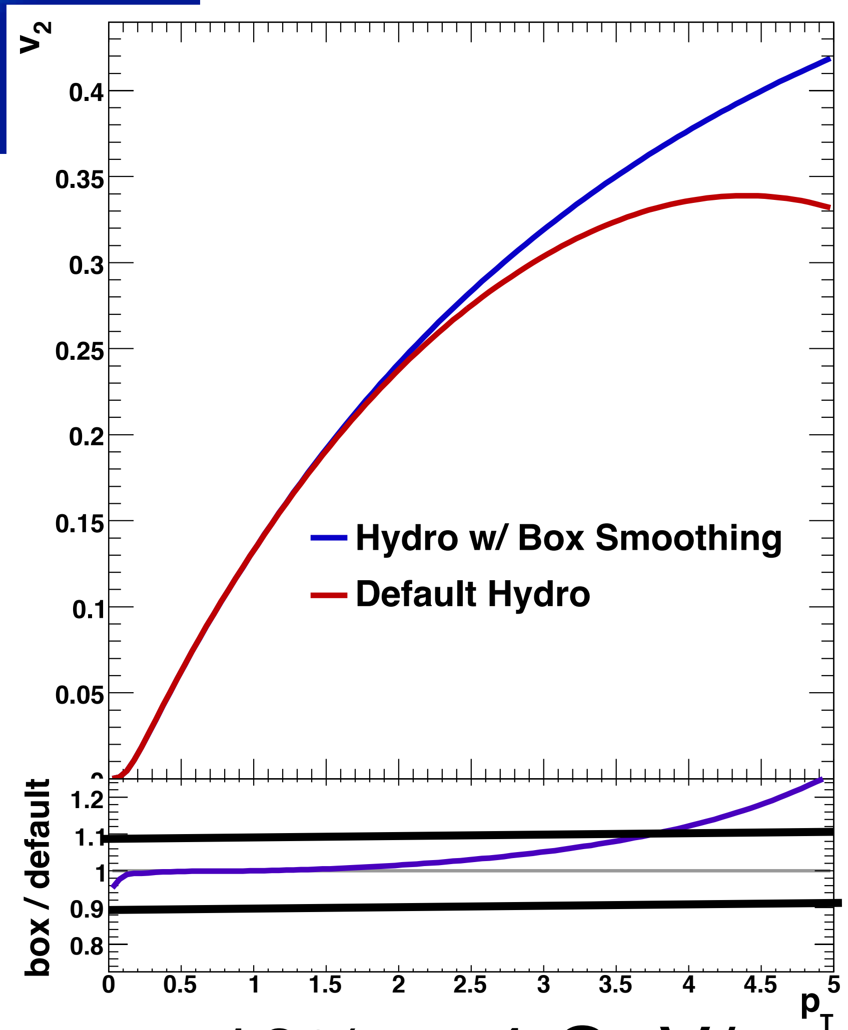
(2) Freeze-out hyper-surface

Technical:

current algorithm assumes simple
“almond” geometry

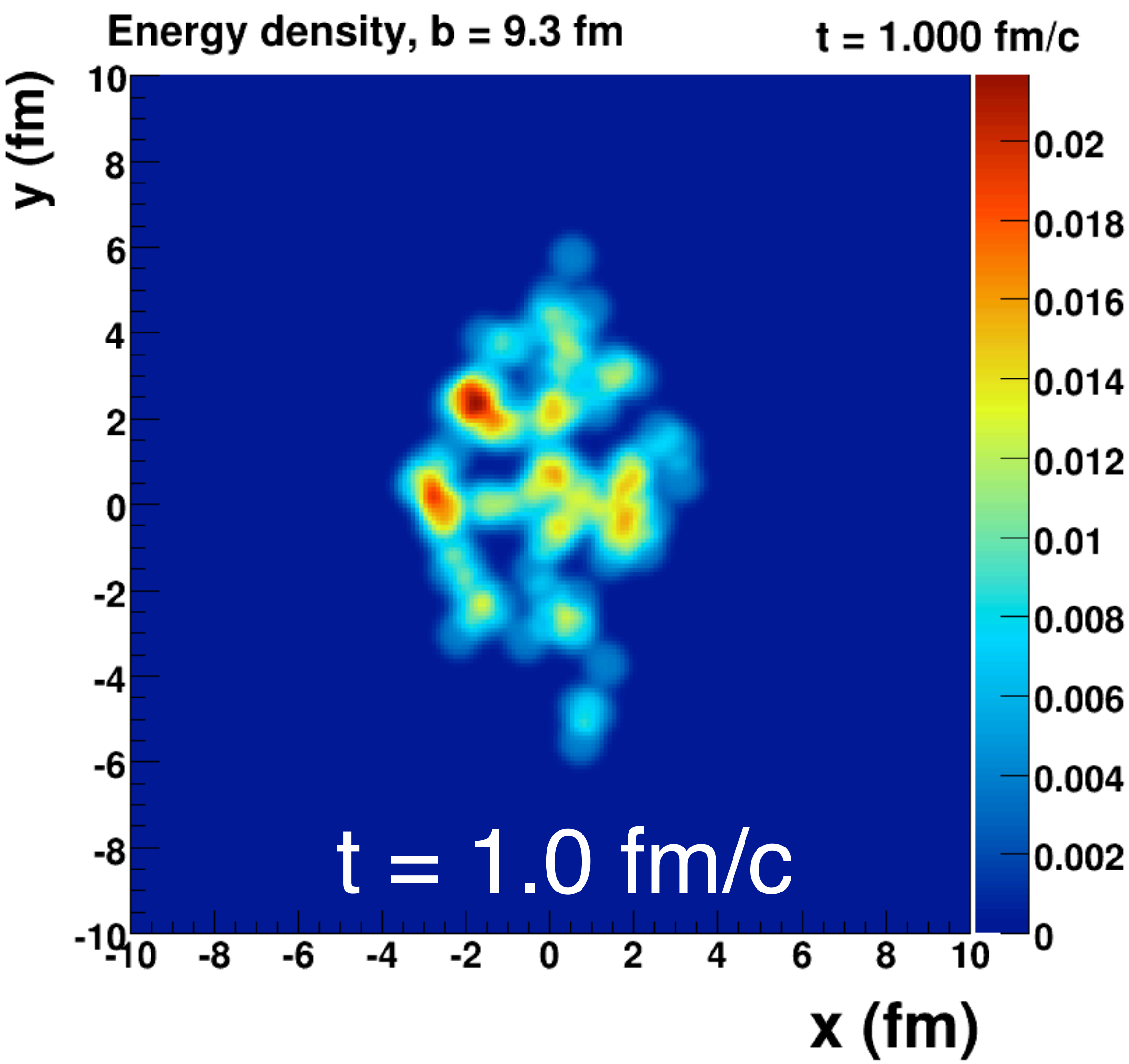
Conceptual:

non-monotonic temperature variation
freezout trajectory may re-enter



10% at 4 GeV/c

Simulation with Fluctuations



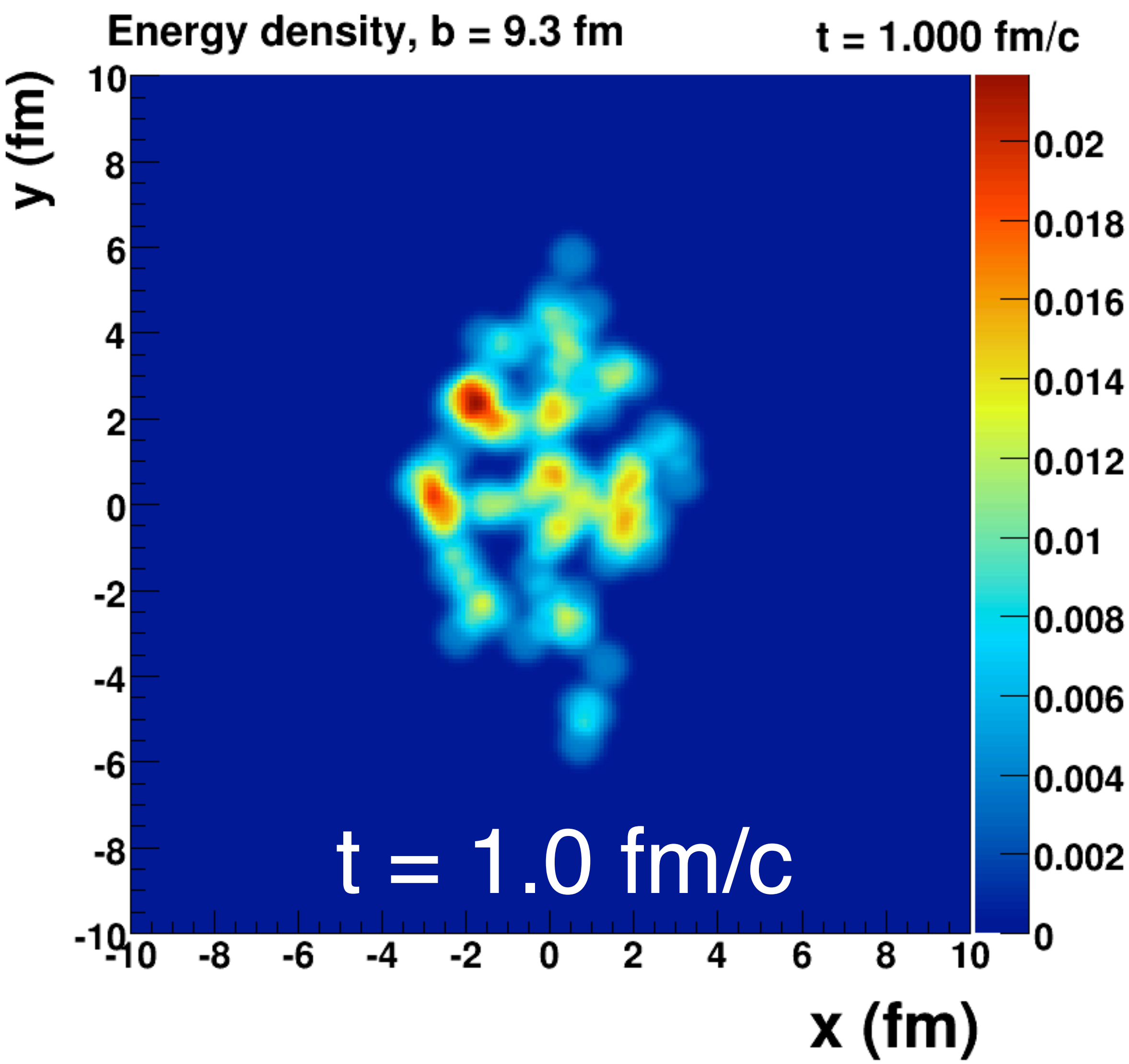
Hydro <u>can</u> be run on fluctuating initial conditions

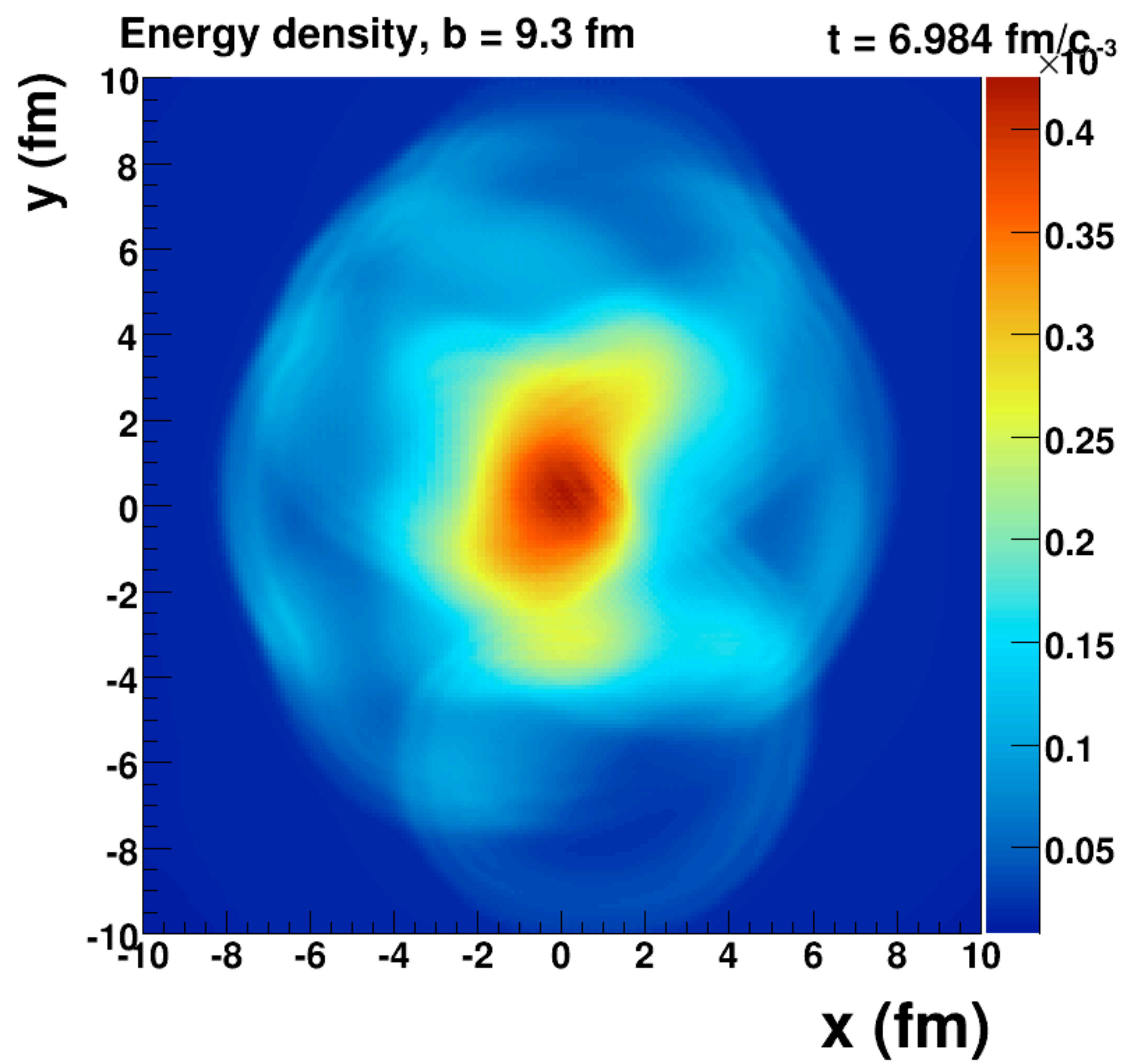
Collective behavior is preserved

Significant event fluctuations persist to final state

Note: “Pulsing” artifact of scaling to peak density

Simulation with Fluctuations





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Outlook

Easier problems:

More elegant (read: correct) solution to numerical error should be possible

Treatment of isolated, possibly non-thermal areas (applies to smooth hydro too!)

Tough problem: defining the freezeout hypersurface

Immediate goal: Simulate multiple collisions (~20 evts) and investigate

extract: $\langle v_2 \rangle$, $\langle v_3 \rangle$, $\langle v_4 \rangle$

compute: v_2 ➡ $\Delta(\eta/s)$, v_3 ➡ c_3^{AB}

<u>Farther out:</u>

Run multiple sets at spanning η/s

→ best fit η/s

→ turbulence scale ($\Delta v_2/v_2$ x η/s)

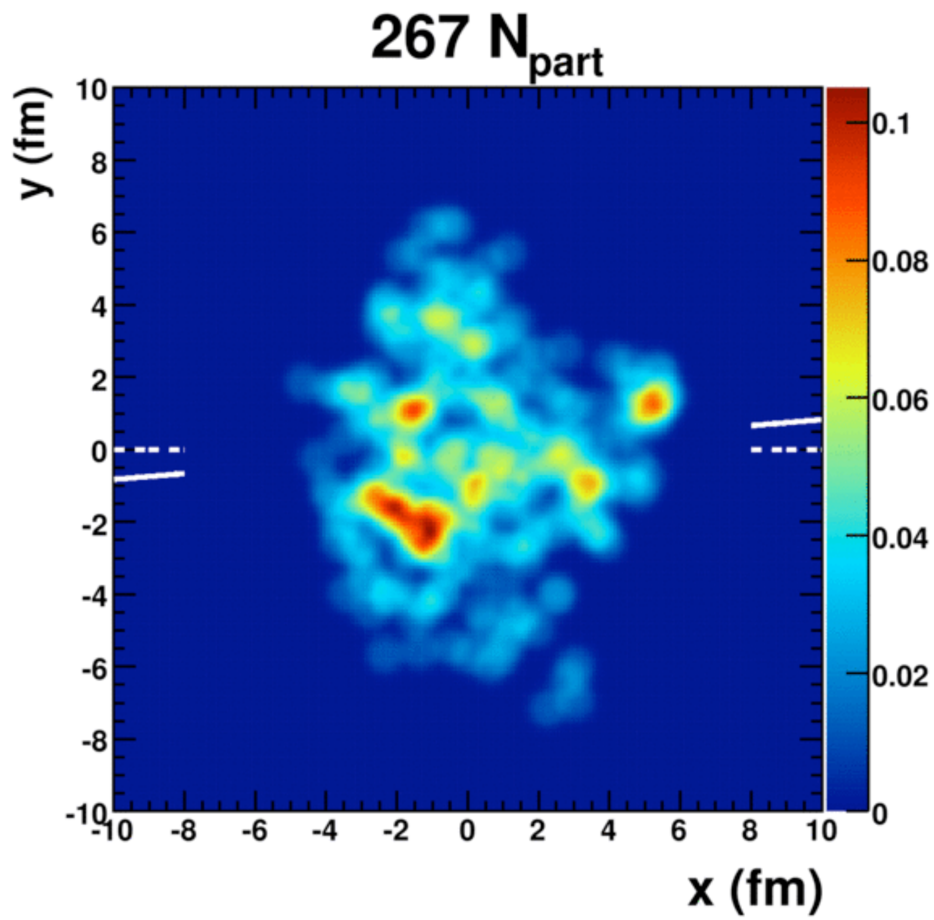
Repeat for spans of x-value, CGC (MC-KLN)

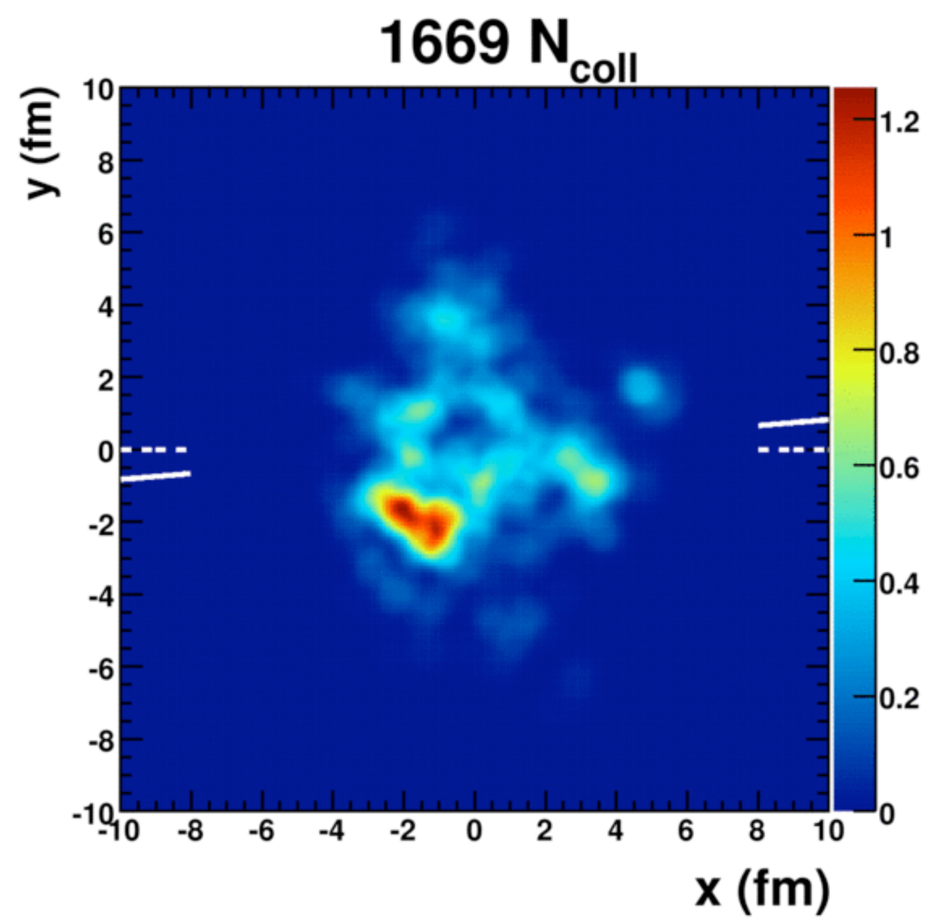
The End

Additional Slides

Random Selections

Central





Mid-central